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ASD TECHNICAL REPORT 61-587

The Drag of Cones, Plates, and Hemispheres in the Wake of a Forebody in Subsonic Flow

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DECEMBER 1961

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The Drag of Cones, Plates, and Hemispheres in the Wake of a Forebody in Subsonic Flow

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and
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Department of Aeronautics and Engineering Mechanics
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December 1961

Flight Accessories Laboratory
Contract No. AF 33(616)-8310
Project 6065
Task 60252

Aeronautical Systems Division
Air Force Systems Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

100 - February 1962 - 21-890

FOREWORD

This report was prepared by the Department of Aeronautics and Engineering Mechanics of the University of Minnesota in compliance with Air Force Contract No. 33(616)-8310.

The work being accomplished under this contract is sponsored jointly by QM Research and Engineering Command, Department of the Army; Bureau of Naval Weapons, Department of the Navy; and Air Force Systems Command, Department of the Air Force; and is directed by a Tri-Service Steering Committee concerned with Aerodynamic Retardation. Contract administration is conducted by the Aeronautical Systems Division and Mr. Rudi J. Berndt of the Aerodynamic Decelerator Branch, Flight Accessories Laboratory, Aeronautical Systems Division, is Project Engineer.

This project was carried out in cooperation with Mr. Ronald J. Niccum, B.S.Ae., and several graduate and undergraduate students, and the authors wish to express their appreciation to them.

ABSTRACT

The drag of a number of bodies having some resemblence to aerodynamic deceleration devices was measured in free stream and in the wake of an ogival cylinder. The diameter ratio of the wake producing body and the deceleration devices as well as the distance between the two bodies was varied.

With the exception of the sphere, the drag of the deceleration device located in the wake is less than its free stream drag.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

George A. Solt, Jr.
Chief, Retardation and Recovery Branch
Flight Accessories Laboratory

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LIST OF SYMBOLS

C_D	=	Drag coefficient of an object located in the wake of a forebody
C_{D_∞}	=	Drag coefficient of an object located in free stream
C_D/C_{D_∞}	=	Drag efficiency
C_p	=	$\Delta p/q$ = pressure coefficient
D	=	Diameter of ogival cylinder
D_p	=	Diameter of primary
D_s	=	Diameter of secondary
L	=	Distance from rear point of primary body to front point of secondary body
M	=	Mach number
Δp	=	Difference between wake total and free stream static pressures
q	=	Free stream dynamic pressure
Re	=	Reynolds number based on D_s and V
r	=	Radius of wake
V	=	Free stream velocity
X	=	Distance downstream from base of ogival cylinder

SECTION I

INTRODUCTION

Intuitively it can be assumed that in general the drag of an object, called secondary body, located in the wake of another object, called primary or forebody, will be less than the drag of the same object in undisturbed flow. This phenomenon is important for problems of aerodynamic deceleration, and it is the objective of this study to establish experimentally the ratio between the free stream and the wake drag of a number of bodies as a function of their location, with the diameter ratio between primary and secondary body as parameter.

The pressure distribution in the wake of the primary body has been measured and is presented in Fig 5. This problem has been treated more extensively in Refs 1 and 2.

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SECTION II

MODELS AND TEST ARRANGEMENT

The forebody used in this study is a cylinder with a 2.5 caliber tangent ogival nose and blunt tail. The overall fineness ratio of this body is 4.5 (Fig 1).

The related secondary bodies are a hollow hemisphere, a sphere, a flat plate, a 45° cone , a 30° cone, and a truncated 45° cone (Fig 2). The diameter of the projected area of all secondary models was five inches.

The drag relationships were investigated for diameter ratios of the primary to secondary bodies of 1:1, 1:2, and 1:3, respectively. Since several different secondary bodies but only one primary body were involved, three primary bodies having diameters of D = 1.67, 2.5, and 5 inches were fabricated and used to obtain the desired diameter ratios.

This procedure had the advantage that in the course of the experiments the drag to be measured for each individual secondary body varied over a relatively small range.

The general test arrangement is shown in Fig 3. The supporting strut of the secondary body contains a strain gage force sensing element shown in Fig 4. This element in connection with an oscillograph was used to record the drag of the secondary body. The strain gage drag recording was chosen because the available mechanical balance was unsatisfactory when the models had a tendency to vibrate; this was particularly noticeable when aerodynamically unstable objects were suspended.

The free stream drag of the secondary bodies was measured in the same manner except that the forebody was removed. The drag coefficient of the secondary body was in all cases related to its projected area and the dynamic pressure of the undisturbed flow.

The wind tunnel used for these experiments was a horizontal, return flow type with test section dimensions of 38 x 54 inches. The Reynolds number of the experiments related to the diameter of the secondary body was approximately 5.2×10^5 at a Mach number of 0.2.

In order to eliminate the influence of the sting mount and supporting strut, so-called tare and interference measurements were made (Ref 3), and the values shown in Figs 6 through 11 are corrected for these effects and represent aerodynamic data related to the objects in free flight. The drag coefficient of the ogive cylinder was determined by measuring the change of momentum of the undisturbed flow (Ref 5).

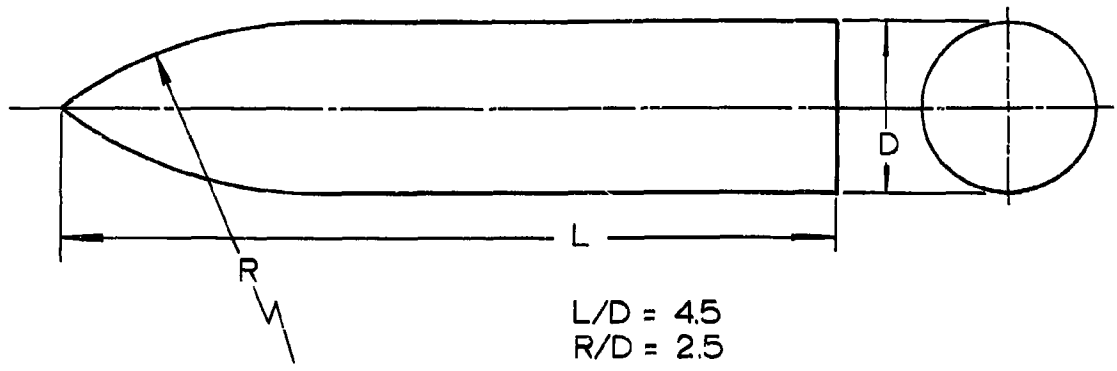
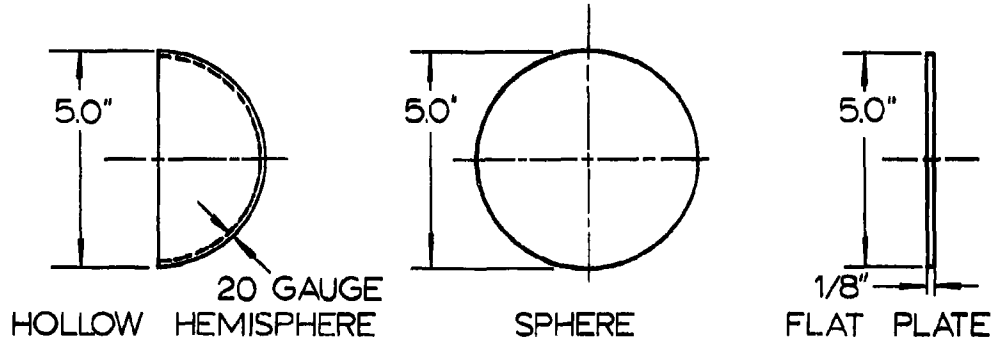


FIG 1. PRIMARY BODY



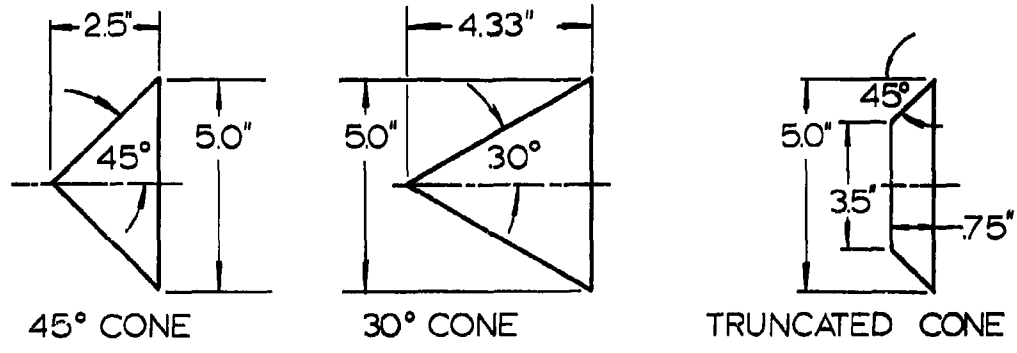


FIG 2. SECONDARY BODIES

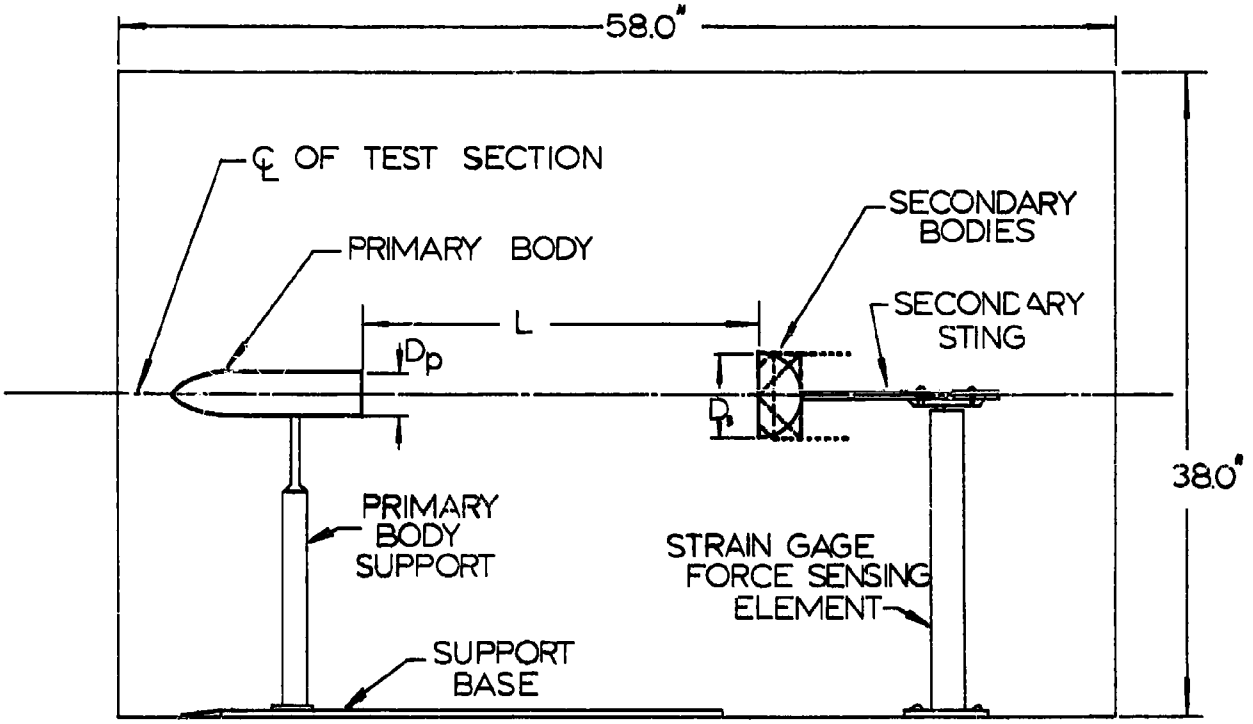


FIG 3. TEST ARRANGEMENT

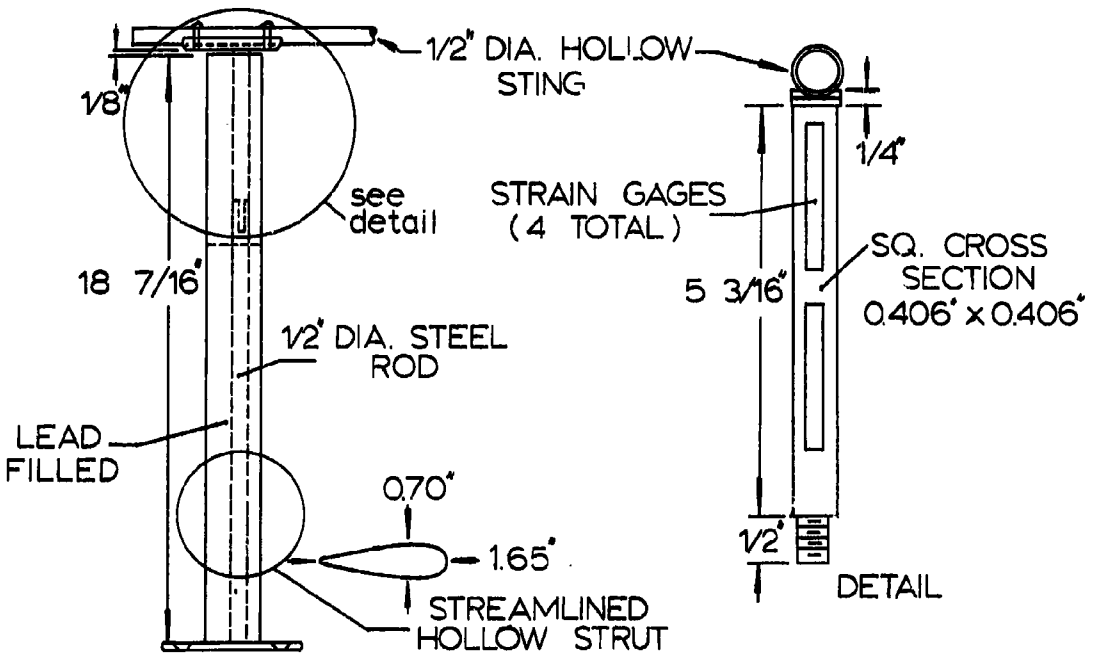


FIG 4. STRAIN GAGE FORCE SENSING ELEMENT

SECTION III

RESULTS

The results of the measurements are shown in Figs 6 through 11 and in Table I. In general, it can be seen that the drag of the secondary body increases with both distance behind the forebody and decreasing forebody diameter. The drag in the wake also approaches the free stream drag at certain distances downstream from the forebody. An exception to this rule can only be found in the configuration where a sphere is used as secondary body, and this case will be discussed separately.

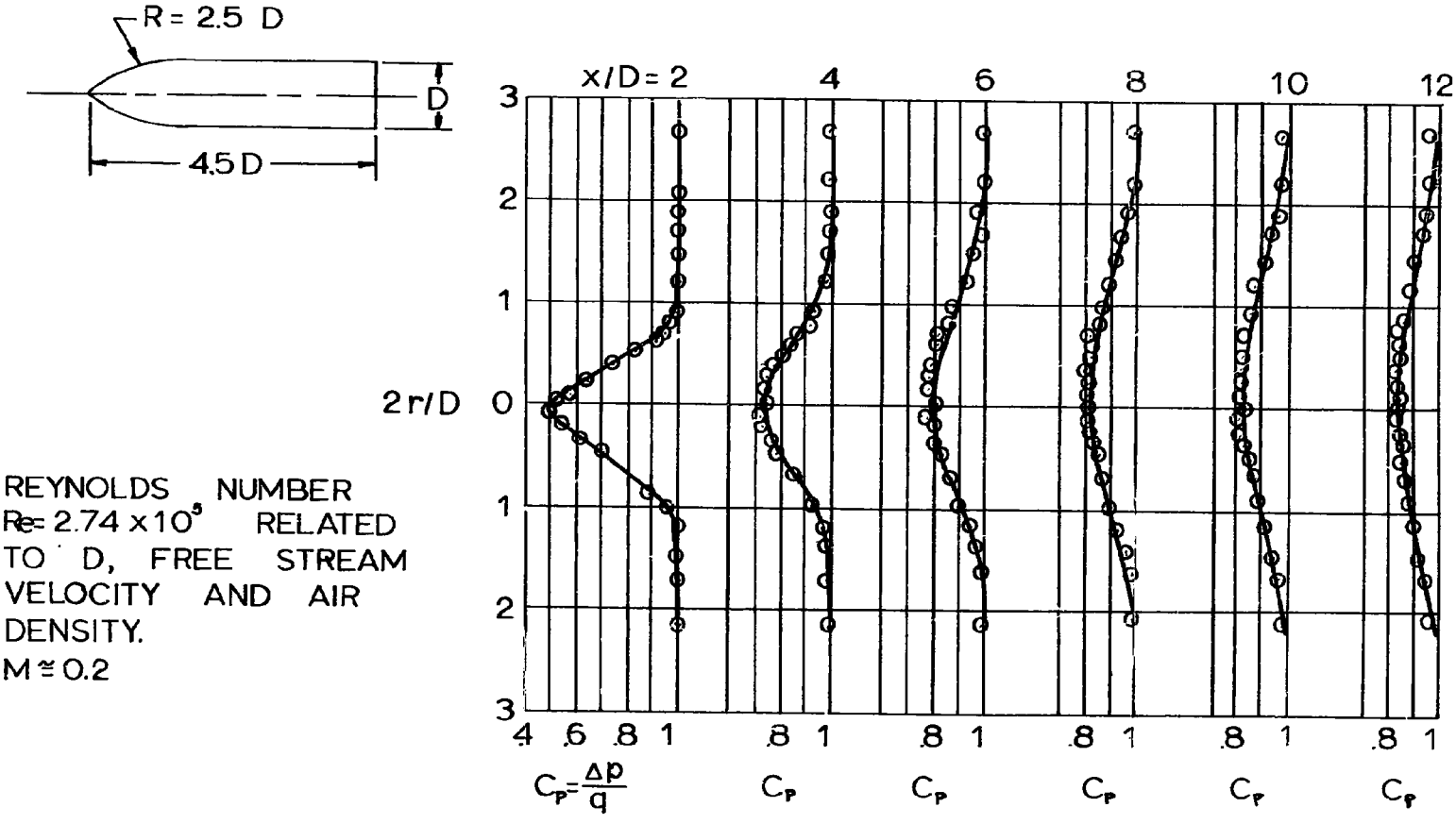
Figure 5 shows the pressure distribution in the wake of the ogive cylinder. It is known that the analysis of the turbulent wake poses certain difficulties and all solutions related to this problem include an emperical factor which is in someway related to Prandtl's "mixing length." Placing now a secondary body in the wake alters, of course, the pressure distribution in the wake ahead of and behind the secondary body, and one obtains a wake problem which is much more complex.

The drag coefficient of the secondary body located at any distance behind the forebody could be determined by measuring the loss of momentum of the flow caused by the secondary body. Unfortunately, an experimental survey of the wake of a combination of bodies is not available at this time, and for an analytical treatment of a wake of this type such a survey may be necessary.

In view of the complexity of the problem of the drag of a body immersed in the turbulent wake of a forebody, it appears that the length to diameter ratio of the secondary body and the eventual existance of a strong variation of its drag coefficient with Reynolds number are significant characteristics in the arrangement of the experimental results. Therefore, the discussion of the results may begin with the review of the measurements of the secondary bodies with minimum length, namely, the flat circular plate and the truncated cone (Figs 6 and 7).

The results of the measurements on the flat plate and the truncated cone show results with tendencies one intuitively would expect.

The next group, the 45° and 30° cones, are characterized by a length of 0.5 to 0.866 base diameters. These bodies are not as blunt as the preceding two, and in fact the 30° cone may already be considered as somewhat streamlined. Therefore, the wake which they produce as well as their influence upon the wake profile between the primary and secondary body will



REYNOLDS NUMBER
$Re = 2.74 \times 10^5$ RELATED TO D, FREE STREAM VELOCITY AND AIR DENSITY.
$M \cong 0.2$

FIG 5. EXPERIMENTAL PRESSURE DISTRIBUTION IN THE WAKE OF A BODY OF REVOLUTION ($C_D = 0.35$)

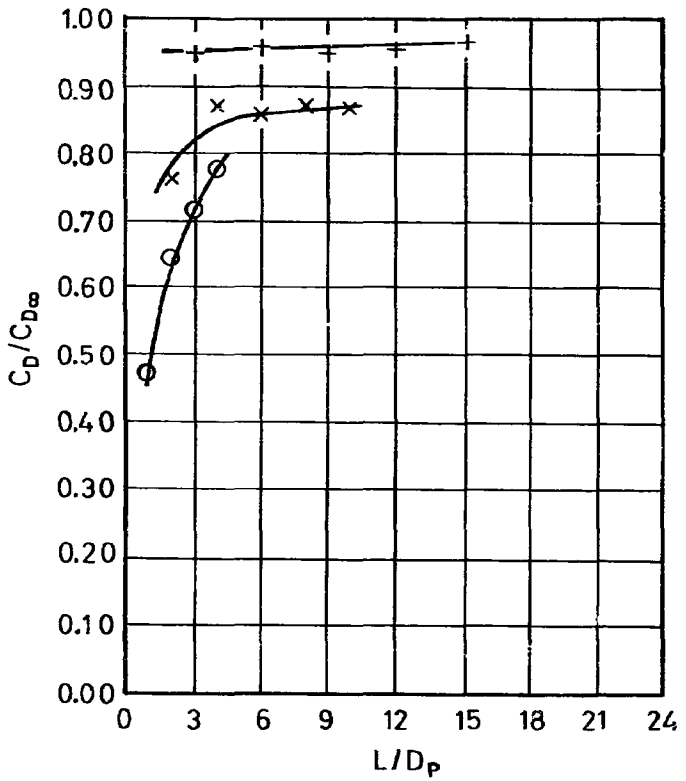


FIG 6. VARIATION OF DRAG EFFICIENCY, $C_D/C_{D\infty}$, WITH L/D_P FOR A FLAT PLATE

$Re = 5.2 \times 10^5$, $M = 0.2$, $C_{D\infty} = 1.125$

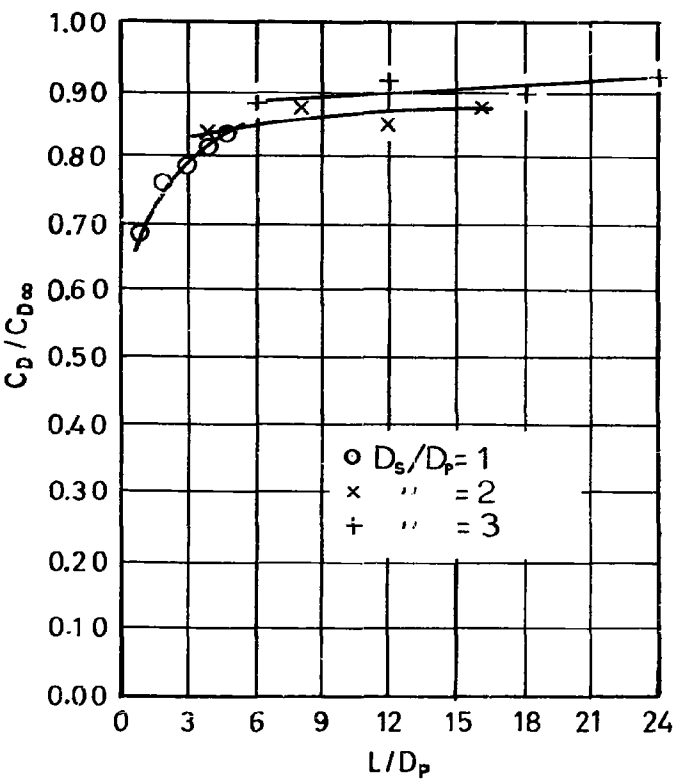


FIG 7. VARIATION OF DRAG EFFICIENCY, $C_D/C_{D\infty}$, WITH L/D_P FOR A TRUNCATED CONE

$Re = 5.2 \times 10^5$, $M = 0.2$, $C_{D\infty} = 0.823$

be considerably different than the effects developed by the blunter bodies.

Reviewing Figs 8 and 9 one observes that the shorter cone has drag characteristics somewhat similar to the preceding two bodies while the longer cone deviates from the relatively simple pattern of its predecessors.

The 30° cone has been measured three times and the experimental results may be considered as reasonably accurate. The quantitative analysis of these data will be subject to a separate investigation.

The results of the measurements encompassing the hollow hemisphere are shown in Fig 10. This body develops a strong individual wake and causes a noticeable pressure rise upstream of its frontal area. Otherwise the hollow hemisphere is a body with a length to diameter ratio of 0.5 as is the 45° cone , and its drag characteristic is somewhat similar to that of the 45° cone except that the drag of the hemisphere in the wake is generally higher. A very particular effect can also be observed for the hemisphere having a diameter ratio of 2. The elevated drag level and the inconsistency in regard to the relative sizes can probably be attributed to the interaction of the two wakes and the effect of the upstream stagnation of the hollow hemisphere.

The drag of the sphere as secondary body is presented in Fig 11. It can be seen that its free stream drag is always smaller than the drag in the wake. The free stream drag coefficient of the sphere was measured to be $C_D = 0.105$ at a Reynolds number of 5.2×10^5 which would indicate that the flow around the sphere was supercritical. However, when this sphere is placed in the wake, the local velocity, and thus the local Reynolds number are considerably reduced and the flow may become subcritical.

Considering the velocity conditions in the wake, a probable drag ratio C_D/C_{D_∞} versus L/D_p for the sphere was obtained in the following manner. By using the velocity on the centerline in the wake of the primary body as shown in Fig 5 and assuming this to be the velocity the sphere experiences at that particular point in the wake, a Reynolds number was calculated for each position. Then, from a C_D versus Re relationship for a moving sphere in resting air, as shown in Ref 4, a drag ratio C_D/C_{D_∞} was calculated for each point. This method also yielded drag ratios higher than unity as illustrated in Fig 11. Therefore, the fact that in this model configuration, C_D/C_{D_∞} is greater than unity appears to be explainable as a Reynolds number dependency.

The measurements encompassing the sphere were very difficult to perform; in particular, the repeatability was not good. This is probably a consequence of the very sensitive

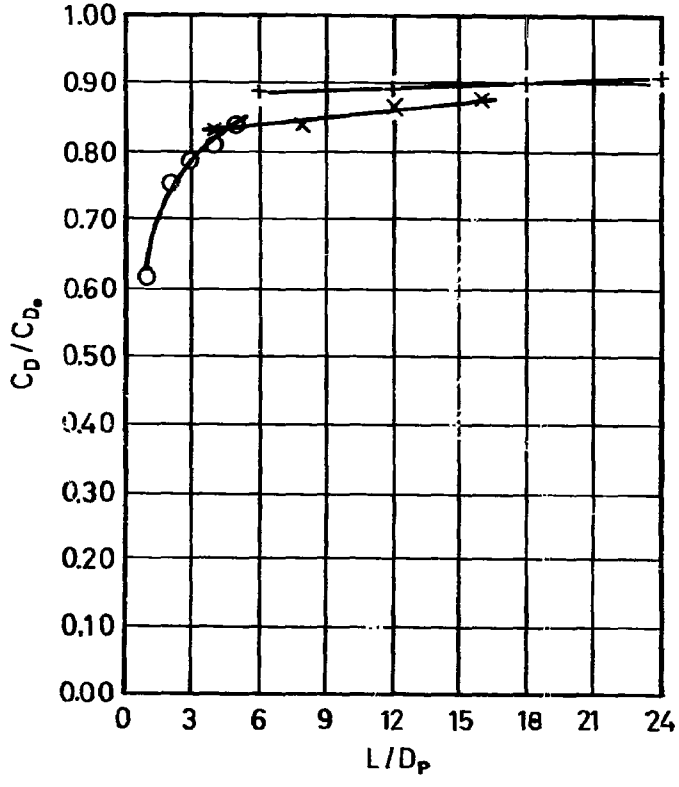


FIG 8. VARIATION OF DRAG EFFICIENCY, $C_D/C_{D\infty}$, WITH L/D_P FOR A 45° CONE

Re = 5.2×10^5, M = 0.2, $C_{D\infty}$ = 0.720

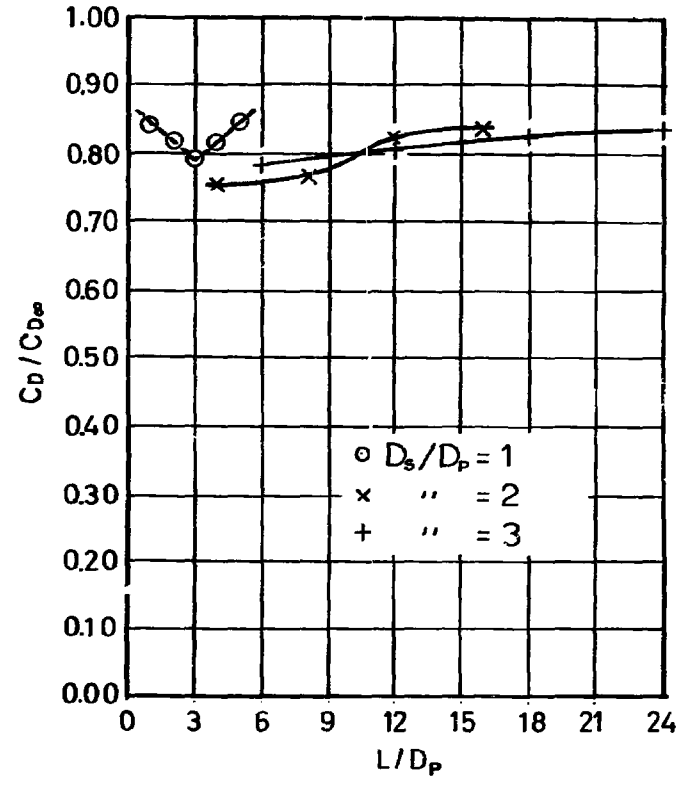


FIG 9. VARIATION OF DRAG EFFICIENCY, $C_D/C_{D\infty}$, WITH L/D_P FOR A 30° CONE

Re = 5.20×10^5, M = 0.2, $C_{D\infty}$ = 0.583

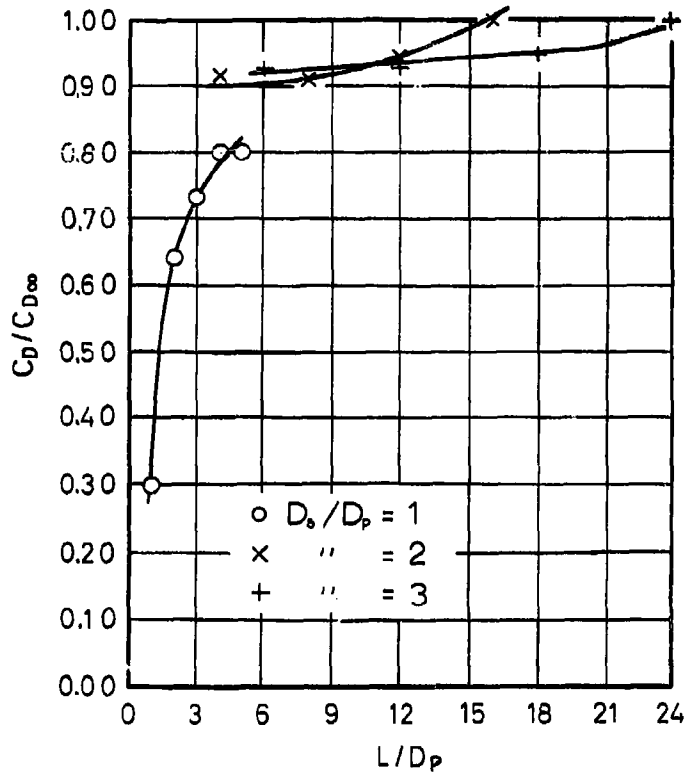


FIG 10. VARIATION OF DRAG EFFICIENCY, $C_D/C_{D\infty}$, WITH L/D_p FOR A HEMISPHERE

$Re = 5.2 \times 10^5$, $M = 0.2$, $C_{D\infty} = 1.52$

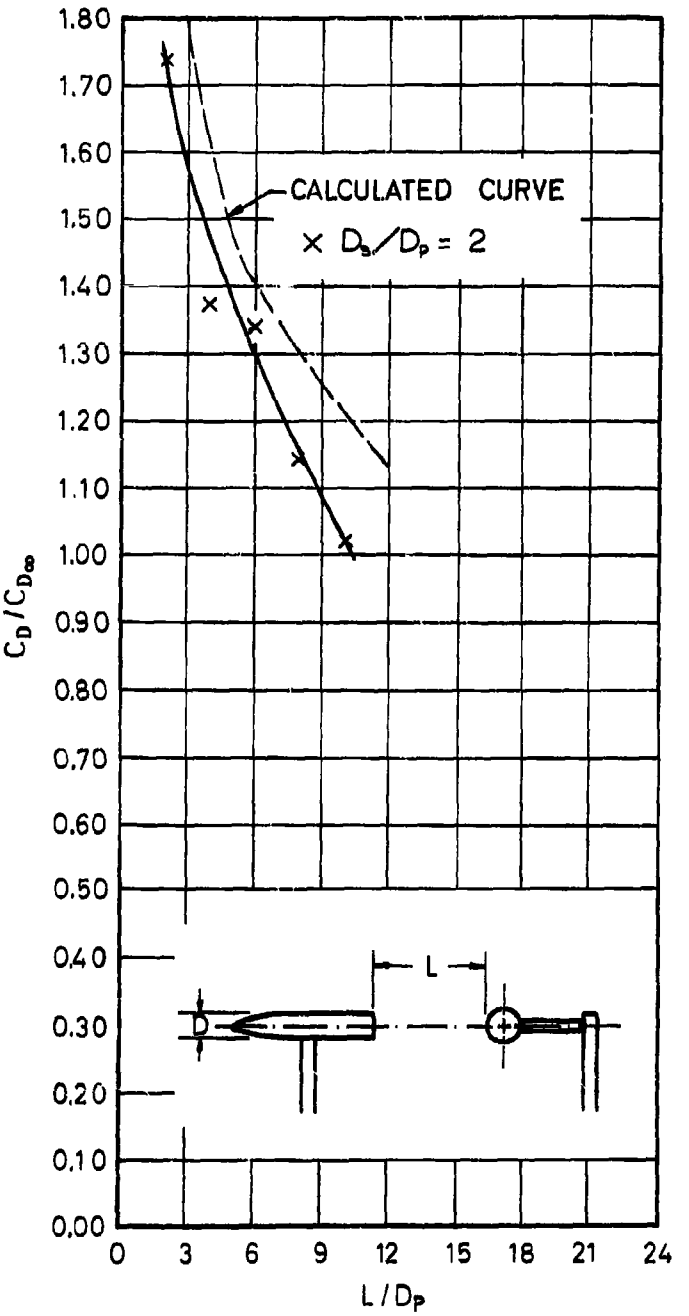


FIG 11. VARIATION OF DRAG EFFICIENCY, $C_D / C_{D\infty}$, WITH L/D_p FOR A SPHERE

$Re = 5.2 \times 10^5$, $M = 0.2$, $C_{D\infty} = 0.105$

nature of the flow pattern of a sphere near its critical Reynolds number. Since it was felt that a detailed and special study of this Reynolds number effect would be required, eventually in connection with a wake survey of a combination of bodies, further measurements involving a sphere were abandoned.

In most experiments discussed above and especially in the tests involving the blunt bodies, such as the flat plate and the hollow hemisphere, considerable vibration of the secondary body was encountered. This made the drag measurements rather difficult. From the dispersion of the recorded data a possible error in the order of $\pm$ 3 per cent may be expected in the presented results. The magnitude of the data, however, is considered reliable, particularly, the tendencies of decreasing influence of the forebody with increasing distance and size of the secondary body.

The presented data are merely experimental, but they indicate the existance of very complicated interactions, and a further exploration of the wake problem of a combination of two bodies appears to be very desirable.

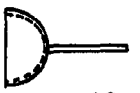
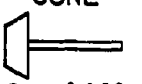
$\frac{D_s}{D_p}$	$\frac{L}{D_p}$	MODELS				
		HEMISPHERE  C_{D_∞}= 1.520	FLAT PLATE C_{D_∞}= 1.125	45° CONE C_{D_∞}= 0.720	30° CONE C_{D_∞}= 0.583	TRUNCATED CONE  C_{D_∞}= 0.823
1	1	0.300	0.471	0.622	0.841	0.694
	2	0.639	0.640	0.755	0.820	0.760
	3	0.738	0.725	0.790	0.791	0.795
	4	0.798	0.780	0.811	0.821	0.815
	5	0.800		0.840	0.852	0.831
2	2		0.758			
	4	0.917	0.875	0.826	0.755	0.829
	6		0.861			
	8	0.907	0.876	0.841	0.769	0.883
	10		0.870			
	12	0.942		0.864	0.825	0.850
	16	1.000		0.887	0.842	0.881
3	3		0.950			
	6	0.931	0.957	0.889	0.798	0.885
	9		0.950			
	12	0.934	0.963	0.890	0.805	0.916
	15		0.966			
	18	0.949		0.900	0.834	0.902
	24	1.000		0.907	0.841	0.925

TABLE I. DRAG EFFICIENCIES, C_D/C_{D_∞}, FOR FIVE BASIC RETARDATION DEVICES IN THE WAKE OF A FOREBODY. M=0.2

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